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ETEC 474

Hardware Description

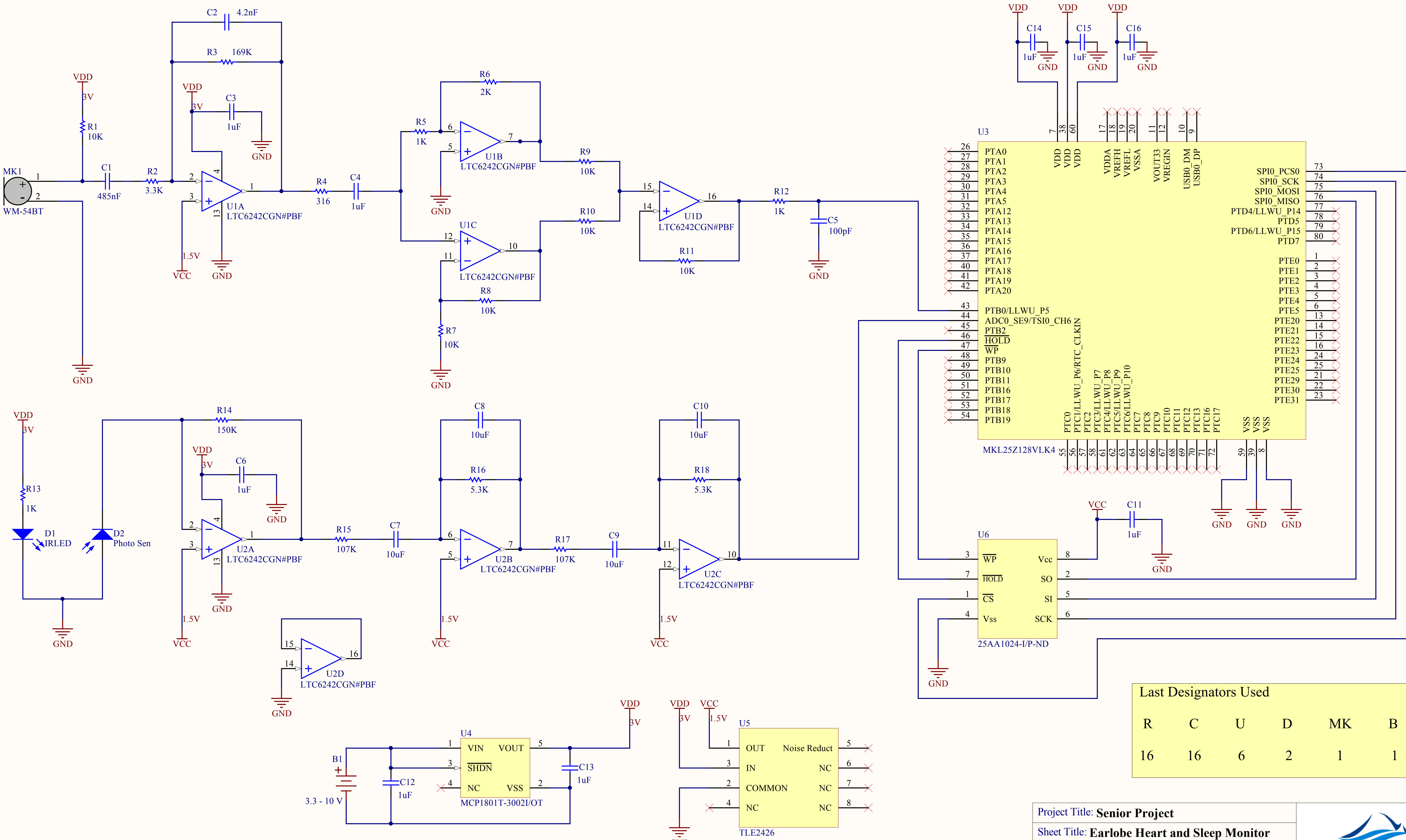
For my Senior Project I am designing the Earlobe Heart and Sleep Monitor. This project incorporates two main modules to observe the users heart rate for anomalies and to listen in for snoring during the night. Both of these modules use low noise CMOS op-amps for precision measurements and rail to rail operation. The schematic provided in this document package will now be described in further detail.

This project will be battery powered by a separately charged 6.4V rechargeable Lithium Iron Phosphate (LiFePO4) battery. Since many of the parts in this project run off 3V, I am using the MCP1801 3V LDO regulator. I chose to use a LDO so that the system can accept a larger range of size of batteries. C10 and C11 are in place to ensure a stable input and output. Since this is a battery powered medical device, the used op-amp's rails cannot swing down to negative voltages. To fix this problem I am using the TLE2426 virtual ground/ precision voltage splitter with a 3V input, from the MCP1801 and provides a 1.5V output. By using this part, all the op-amps reference pins connect to the TLE2426 1.5V output and the negative rails are connected to ground.

For the microphone circuit I chose to use an electret condenser microphone. A condenser microphone is ideal for my application for a couple of reasons, including its small package size. The other reason I chose to use a condenser microphone is due to the fact that they are inherently low power and are easily adapted for battery applications. The microphone circuit uses four op-amps in multiple stages to band pass filter the small signal input with gain, rectify the amplified signal, and the final stage to complete the rectification. The microphone itself does require a small current to operate; this is the function of R1 in the schematic. The current running through the microphone is limited to 0.5 mA, which is just below the maximum current consumption for this part so that it cannot burn out under normal conditions. Capacitor C1 and resistor R2, as well as the feedback components C2 and R3 compose the band-pass filter network with gain. After researching online I came to the conclusion that the high-pass frequency of 100 Hz combined with the low-pass frequency of 500 Hz would be adequate to capture the average snorer and eliminate most outside noises. Through trial and error I found that if I balanced the resistors R2 and R3 to have a gain of about -51 that the microphone circuit will pick up a user's snore, but not heavy breathing. This in turn also does a decent job of eliminating other noises. Negative feedback was used as it is more stable and keeps the amplifier operating in the linear regime. Capacitor C4 is then used to remove the DC component of the signal before it is split for rectification. After C4 the signal is sent to the parallel op-amps U1B (inverting) and U1C (non-inverting). By doing this, the inverting U1B op-amp effectively takes the negative portion of the signal and flips it above the 0 Volt line. The non-inverting U1C does not invert the signal, then the output of both these op-amps are combined back together and fed through a summing amplifier that uses identical resistors R9 and R10 to generate a fully rectified signal. This rectified signal is very rough, so by adding the low pass filter R12 and C5, I now have a very smooth envelope of the snoring signal. This is now a much easier signal to send to the microcontroller for level detection. If the audio level is above a threshold then the patient is snoring excessively. I feel that it is important to point out that U1A provides most the gain, U1B/C have to have matched gain, but because U1C is non-inverting the lowest gain I could get is 1, however I chose to use a gain of 1.5.

In order to attain a patient's heart rate I implemented a photoplethysmograph. A photoplethysmograph works by observing the change in volume of a bed of tissue to determine a heartbeat. In addition to this, the design can be executed using a reflection or direct light technique. I chose to use the direct light method. With this method infrared light passes from an IR LED (D1) through the patient's earlobe into a photodiode (D2). As the heart beats, there will be a change in volume of red blood cells which absorb this frequency of light and in turn, vary the amount of light the photodiode receives. D1 on the schematic is a near infrared LED with a 940 nm wavelength and is biased at 42 mA with resistor R13 so as to have as bright of a light as possible without burning it out. When photodiodes come in contact with light, they output a certain current, but the MKL25Z128VLK4 MCU requires useable voltages to interpret data. To fix this problem I used U2A in a transimpedance amplifier topology with the photodiode in photovoltaic mode, i.e. D2 outputs a positive current into U2A. The feedback resistor R14 sets the sensitivity of this part at about 150 $\frac{V}{mA}$. This signal now has most of its gain applied to it. This product assumes that the user is either going to sleep or is already asleep, so the average heart rate should be between 40 and 100 BPM. This correlates to a frequency below 1 Hz and no higher than 2 Hz. For this reason, the signal is sent to U2B, which operates as an active band-pass filter with cutoff frequencies 0.15 Hz and 3 Hz. This is sufficient to capture the heart beat signal and filter out most other noise inputs. From here the signal goes through another identical band-pass filter to steepen the cutoff and maintain an inverted signal. This signal is now ready to be sent to the Analog to Digital Converter on the MCU.

A large part of this project is its ability to store valuable collected data. Since this product's battery must be removed to charged, and there is no on board EEPROM, I incorporated Microchip's 25AA1024 serial EEPROM IC. This chip is selected and communicates via SPI bus on the MKL25Z128VLK4 MCU. Pins 3 and 7 are the Write Protect and HOLD pins and are set via GPIO.



Last Designators Used

R	C	U	D	MK	B
16	16	6	2	1	1

Project Title: **Senior Project**

Sheet Title: **Earlobe Heart and Sleep Monitor**

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Index	Manufacturer	MFG P/N	Description	Package/ Case	Qty	Designator
1	Linear Technology	LTC6242CGN#PBF	Quad, Low Noise, CMOS Op-Amp	16-SSOP	2	U1, U2
2	Freescale	MKL25Z128VLK4	System CPU	80-LQFP	1	U3
3	Microchip Technology	MCP1801T-3002I/OT	3V 150 mA Low Quiescent Current LDO Voltage Regulator	SOT-23-5	1	U4
4	Texas Instruments	TLE2426	Precision Virtual Ground	8-SOIC	1	U5
5	Microchip Technology	25AA1024-I/P-ND	1 Mbit SPI Bus Serial EEPROM	8-SOIC	1	U6
6	Panasonic Electronic Components	WM-54BT	Electret Condenser Microphone	Thru hole 0.1" , 9.70mm Dia.	1	MK1
7	AA Portable Power Corp	LFP-6.4V0.8Ah-18500	6.4V LiFePO4 800mAh Battery	2 x 18500 Cells	1	B1
8	Lite-On Inc	LTE-4208	940 nm Infrared LED	3mm	1	D1
9	TT Electronics	OP-999	Narrow Receiving Angle Photodiode	3mm	1	D2
10	Panasonic Electronic Components	ERA-3AEB103V	10 KΩ Res. 1% 1/10W	0603 (1608 metric)	6	R1, R7, R8, R9, R10, R11
11	Panasonic Electronic Components	ERA-3AEB102V	1 KΩ Res. 1% 1/10W	0603 (1608 metric)	3	R5, R12, R13
12	Panasonic Electronic Components	ERA-3AEB332V	3.3 KΩ Res. 1% 1/10W	0603 (1608 metric)	1	R2
13	Panasonic Electronic Components	ERJ-3EKF1693V	169 KΩ Res. 1% 1/10W	0603 (1608 metric)	1	R3
14	Panasonic Electronic Components	ERJ-3EKF3160V	316 Ω Res. 1% 1/10W	0603 (1608 metric)	1	R4
15	Panasonic Electronic Components	ERJ-3EKF2001V	2 KΩ Res. 1% 1/10W	0603 (1608 metric)	1	R6
16	Panasonic Electronic Components	ERA-3AEB154V	150 KΩ Res. 1% 1/10W	0603 (1608 metric)	1	R14
17	Panasonic Electronic Components	ERA-3AEB1073V	107 KΩ Res. 1% 1/10W	0603 (1608 metric)	1	R15
18	Panasonic Electronic Components	ERJ-6ENF5361V	5.3 KΩ Res. 1% 1/10W	0603 (1608 metric)	1	R16
19	AVX	06036D105KAT2A	1 uF 6.4V Ceramic Cap. 10%	0603 (1608 metric)	7	C3, C4, C6, C9, C10, C11, C12
20	Murata Electronics North America	GRM188R60J106ME47D	10 uF 6.4V Ceramic Cap. 20%	0603 (1608 metric)	2	C7, C8
21	KEMET	C0603C101K5GACTU	100 pF 50V Ceramic Cap. 10%	0603 (1608 metric)	1	C5
22	KEMET	C0603C474K4RACTU	0.47 uF 16V Ceramic Cap. 10%	0603 (1608 metric)	1	C1
23	Murata Electronics North America	GRM1887U1H432JA01D	4300 pF 50V Ceramic Cap. 5%	0603 (1608 metric)	1	C2